ASCA OBSERVATIONS OF THE GALACTIC BULGE HARD X–RAY SOURCE GRS 1758–258

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ABSTRACT

GRS 1758–258 is one of the few persistent hard X–ray emitters ($E > 100$ keV) in the Galaxy. Using the ASCA satellite, we have obtained the first detailed data on GRS 1758–258 in the 1–10 keV range, where previous observations were affected by confusion problems caused by the nearby strong source GX5–1. The spectrum is well described by a power law with photon index 1.7 without strong Fe emission lines. A prominent soft excess, as observed with ROSAT when the hard X–ray flux was in a lower intensity state, was not detected. However, the presence of a soft spectral component, accounting for at most 5% of the 0.1–300 keV flux, cannot be excluded. The accurate measurement of interstellar absorption ($N_H = (1.5 \pm 0.1) \times 10^{22}$ cm $^{-2}$) corresponds to an optical extinction which definitely excludes the presence of a massive companion.

Subject headings: X-Rays: Stars – Stars: individual (GRS 1758–258) – Black holes

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1. Introduction

The source GRS 1758–258 was discovered in the hard X–ray/soft γ–ray energy range with the SIGMA/GRANAT coded mask telescope (Sunyaev et al. 1991). GRS 1758–258 is of particular interest since, together with the more famous source 1E 1740.7– 2942, it is the only persistent hard X–ray emitter ($E > 100$ keV) in the vicinity of the Galactic Center (Goldwurm et al. 1994). Both sources have peculiar radio counterparts with relativistic jets (Mirabel et al. 1992a; Rodriguez, Mirabel & Martì 1992; Mirabel 1994) and might be related to the 511 keV line observed from the Galactic Center direction (Bouchet et al. 1991). Despite the precise localization obtained at radio wavelengths, an optical counterpart of GRS 1758–258 has not been identified (Mereghetti et al. 1992; Mereghetti, Belloni & Goldwurm 1994a). Simultaneous ROSAT and SIGMA observations, obtained in the Spring of 1993, indicated the presence of a soft excess (Mereghetti, Belloni & Goldwurm 1994b). This spectral component ($E < 2$ keV) was weaker in 1990, when the hard X–ray flux ($E > 40$ keV) was in its highest observed state. On the basis of its hard X–ray spectrum, GRS 1758–258 is generally considered a black hole candidate (Tanaka & Lewin 1995; Stella et al. 1995). The possible evidence for a soft spectral component anticorrelated with the intensity of the hard (> 40 keV) emission supports this interpretation. No detailed studies of GRS 1758–258 in the "classical" X–ray range have been performed so far. Here we report the first observations of this source obtained with an imaging instrument in the $0.5-10$ keV energy range.

2. Data Analysis and Results

The observation of GRS 1758–258 took place between 1995 March 29 22:39 UT and March 30 15:38 UT. The ASCA satellite (Tanaka, Inoue & Holt 1994) provides simultaneuos data in four coaligned telescopes, equipped with two solid state detectors (SIS0 and SIS1) and two gas scintillation proportional counters (GIS2 and GIS3). We applied stringent screening criteria to reject periods of high background, and eliminated all the time intervals with the bright earth within 40 degrees of the pointing direction for the SIS data (10 degrees for the GIS), resulting in the net exposure times given in Table 1.

TABLE 1

	Exposure Time (s)	Count Rate (counts/s)
SIS0	9,471	5.310±0.024
SIS1	9,455	4.220±0.022
GIS2	12,717	4.507±0.022
GIS3	11,949	5.155±0.025

2.1. GIS Data

Figure 1 shows the image obtained with the GIS2 detector. Most of the detector area is covered by stray light due to the bright source GX5–1, located outside the field of view, at an off–axis angle of about 40 arcmin. Fortunately, GRS 1758–258 lies in a relatively unaffected region of the detector, which allows us to estimate the contamination from GX5–1 as explained below. The source counts were extracted from a circle of 6 arcmin radius centered at the position of GRS 1758–258, and rebinned in order to have a minimum of 25 counts in each energy channel. Due to the present uncertainties in the ASCA response at low energies, we only considered photons in the 0.8–10 keV range. The background spectrum was extracted from the corresponding regions of observations of empty fields provided by the ASCA Guest Observer Facility. The contribution to the background due to GX5–1 is mostly concentrated in a circular segment with area ~36 arcmin2 indicated with A in figure 1. Its spectrum was estimated by the difference of regions A and B, and added to the background. A similar procedure was followed to extract the GIS3 net spectrum. Using XSPEC (Version 9.0) we explored several spectral models by simultaneously fitting the data sets of both GIS instruments. The best fit was obtained

with a power law with photon index 1.66 ± 0.03 and column density $N_H = (1.42 \pm 0.04) \times 10^{22}$ cm^{-2} (reduced $\chi^2 = 1.013$ for 372 d.o.f., errors at 90% confidence intervals for a single interesting parameter). Other models based on a single spectral component (e.g. blackbody, thermal bremsstrahlung) gave unacceptable results, with the exception of the Comptonized disk model of Sunyaev & Titarchuk (1980). However, the limited energy range of the ASCA data alone, does not allow in the latter case to pose interesting constraints on the fit parameters.

The GIS instruments have a time resolution of 0.5 s or 62.5 ms, according to the available telemetry rate. Most of our data had the higher time resolution. Using a Fourier transform technique, and after correction of the times of arrivals to the solar system barycenter, we performed a search for periodicities. No coherent pulsations in the 0.125–1000 s period range were found. For the hypothesis of a sinusoidal modulation we can set an upper limit of $\sim$5% to the pulsed fraction.

2.2. SIS Data

Both SIS instruments were operated in the single chip mode, which gives a time resolution of 4 s and images of a square 11x11 arcmin2 region (Figure 2). Most of the SIS data (83%) were acquired in "faint mode" and then converted to "bright". This allows to minimize the errors due to the echo effects in the analog electronics and to the uncertainties in the dark frame value (Otani & Dotani, 1994). The inclusion of the data directly acquired in bright mode resulted in spectra of lower quality (significant residuals in the 2–3 keV region). We therefore concentrated the spectral analysis on the faint mode data. The source counts (0.6–10 keV) were extracted from circles with a radius of 3 arcmin, and the resulting energy spectra (1024 PI energy channels) rebinned in order to have at least 25 counts in each bin. We subtracted a background spectrum derived during our observation from an apparently source free region of the CCDs (see figure 2). This background is higher than that obtained from the standard observations of empty fields, probably due to the contamination from GX5–1. It contributes $\sim$4% of the extracted counts. We verified that the derived spectral parameters do not change significantly if we use the blank sky background file, or even if we completely neglect the background subtraction. By fitting together the data from the two SIS we obtained results similar to those derived with the GIS instruments. In particular, a power law spectrum gives photon index $\alpha = 1.70 \pm 0.03$ and $N_H = (1.55 \pm 0.03) \times 10^{22}$ cm^{-2}, with a reduced χ^2 of 1.031 (872 d.o.f.).

No prominent emission lines are visible in the spectrum of GRS 1758–258 (as already mentioned, some features in the region around 2 keV are probably due to instrumental problems, they appear stronger when the bright mode data and the corresponding response matrix are used). Upper limits on the possible presence of an iron line were computed by adding a gaussian line centered at 6.4 keV to the best fit power law model and varying its parameters (intensity and width) until an unacceptable increase in the c2 was obtained. The 95% upper limit on the equivalent width is $\sim$50 eV for a line width of $\sigma = 0.1$ keV and increases for wider lines (up to $\sim$110 eV for $\sigma = 0.5$ keV).

Also in the case of the SIS, a search for periodicities (limited to period greater than 8 s) resulted only in upper limits similar to the GIS ones.

3. Discussion

The soft X–ray flux observed with ROSAT in 1993 (Mereghetti et al. 1994b) was higher than that expected from the extrapolation of the quasi–simultaneous SIGMA measurement ($E >$ 40 keV), indicating the presence of a soft spectral component with power law photon index $\sim$3 below $\sim$2 keV. Clearly, such a steep, low–energy component is not visible in the present ASCA data, which are well described by a single flat

power law. The corresponding flux of 4.8×10^{-10} ergs cm^{-2} s^{-1} (in the 1–10 keV band, corrected for the absorption) is within the range of values measured in March–April 1990 (Sunyaev et al. 1991), when the source was in its highest observed state. This fact is consistent with the presence of a prominent soft component only when the hard X–ray flux is at a lower intensity level.

Though a single power law provides an acceptable fit to the ASCA data, we also explored spectral models consisting of two different components: a soft thermal emission plus a hard tail. For instance, with a blackbody plus power law, we obtained a good fit to both the SIS and GIS data with $kT \sim 0.4 - 0.5$ keV and photon index $\sim 1.4 - 1.5$ ($\chi^2 \simeq 0.98$). Obviously such a power law must steepen at higher energy to be consistent with the SIGMA observations. In fact a Sunyaev–Titarchuk Comptonization model can equally well fit the ASCA hard tail and provide an adequate spectral steepening to match the high energy data (see Figure 3). Good results were also obtained when the soft thermal component was fitted with models of emission from accretion disks (e.g. Makishima et al. 1986, Stella & Rosner 1984). In all cases the total flux in the soft component amounts only to a few percent of the overall (0.1– 300 keV) luminosity. However, the low observed flux, coupled to the high accretion rates required by the fitted temperatures, implies an unplausible large distance for GRS 1758–258 and/or very high inclination angles (note that there is no evidence so far of eclipses or periodic absorption dips which could hint to a high inclination system). A possible alternative solution is to invoke a significant dilution of the optically thick soft component by Comptonization in a hot corona. A very rough estimate shows that, in order to effectively remove photons from the thermal distribution, a scattering opacity of $\tau_{es} \sim 2 - 5$ is required.

Our ASCA observation provides the most accurate measurement of the absorption toward GRS 1758–258 obtained so far. Obviously the derived value is slightly dependent on the adopted spectral model. However, values within at most 10% of 1.5×10^{22} cm^{-2} were obtained for all the models (one or two components) fitting the data. This column density is consistent with a distance of the order of the Galactic center and similar to that of other sources in the galactic bulge (Kawai et al. 1988), but definitely smaller than that observed with ASCA in 1E 1740.7–2942 (Churazov et al. 1996).

The information on the galactic column density, coupled to the optical/IR data, can yield some constraints on the possible companion star of GRS 1758–258 (see Chen, Gehrels & Leventhal 1994). A candidate counterpart with I ~19 and K ~17 (Mereghetti et al. 1994a) lies within ~2" of the best radio position (Mirabel et al. 1992b). Other infrared sources present in the X–ray error circle (10" radius) are fainter than $K \sim 17$ (Mirabel & Duc 1992). Using an average relation between N_H and optical reddening (Gorenstein 1975), we estimate a value of $A_V \sim 7$, corresponding to less than one magnitude of absorption in the K band (Cardelli, Clayton & Mathis 1989). Thus, for a distance of the order of 10 kpc, the K band absolute magnitude must be fainter than $M_K \sim 1$. This limit clearly rules out supergiant or giant companion stars, as well as main sequence stars earlier than type A (Johnson 1966), thus excluding the possibility that GRS 1758–258 is in a high mass binary system.

The flux of GRS 1758–258 measured with the SIS instruments corresponds to a 1–10 keV luminosity of 4.5×10^{36} ergs s^{-1} (for a distance of 10 kpc). A reanalysis of archival data from TTM/MIR, XRT/Spacelab–2 and EXOSAT (Skinner 1991), showed that GRS 1758–258 had a similar intensity also in 1985 and in 1989. An earlier discovery had been prevented only by confusion problems with GX5–1, much brighter than GRS 1758– 258 below ~20 keV. Subsequent hard X–ray observations with SIGMA (Gilfanov et al. 1993, Goldwurm et al. 1994) repeatedly detected GRS 1758–258 with a hard spectrum extending

up to ∼300 keV. It is therefore clear that GRS 1758–258, though variable by a factor of ∼10 on a timescale of months, is not a transient source.

4. Conclusions

The ASCA satellite has provided the first detailed data on GRS 1758–258 in the 1–10 keV region, allowing to minimize the confusion problems caused by the vicinity of GX5–1, that affected previous observations with non imaging instruments.

The possible black hole nature of GRS 1758–258, inferred from the high energy data (Sunyaev et al. 1991, Goldwurm et al. 1994), is supported by the ASCA results. The power law spectrum, extending up to the hard X–ray domain is similar to that of Cyg X–1 and other black hole candidates in their low (or hard) state. Furthermore, our stringent limits on the presence of periodic pulsations and accurate measurement of interstellar absorption make the possibility of a neutron star accreting from a massive companion very unlikely. The lack of iron emission lines in the SIS data has to be confirmed by more stringent upper limits to rule out, e.g., the presence of a reflection component as proposed for Cyg X–1 (Done et al. 1992). For comparison, the iron line recently observed with ASCA in Cyg X– 1 has an equivalent width of only 10–30 eV (Ebisawa et al. 1996).

The prominent soft excess observed with ROSAT in 1993, when the hard X–ray flux was in a lower intensity state, was absent during our observation. The source was in a hard spectral state, with a possible soft component accounting for ∼5% of the total luminosity at most. A similar soft component ($kT \sim 0.14$ keV), but contributing a larger fraction of the flux, has been observed in Cyg X–1 and attributed to emission from the accretion disk (Balucinska–Church et al. 1995). If the soft component in GRS 1758–258 originates from the disk, strong dilution is required. An optically thick hot cloud embedding the innermost part of the disk is an attractive hypothesis. To test the viability of this model, a detailed fit to simultaneous data over a broad energy range, as available, e.g., with SAX in the near future, is required.

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Fig. 1.— Image of GRS 1758–258 obtained with the GIS2 instrument. The field has a diameter of 50 arcmin. Stray X– rays from GX5–1, located 40 arcmin north of GRS 1758–258, affect mostly part A of the source extraction circle (6' radius).

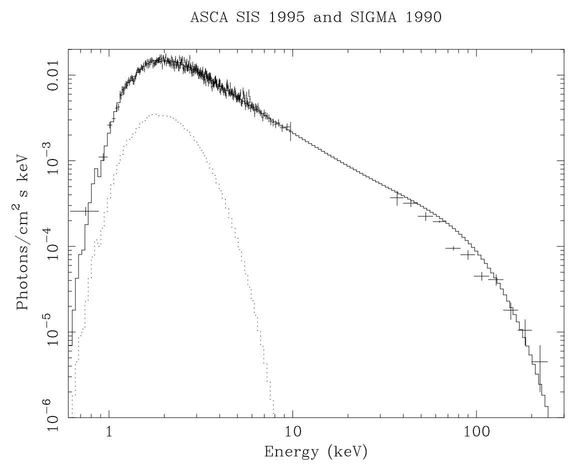

Fig. 2.— SIS0 image of GRS 1758–258. The two circles indicate the source and background extraction regions, with radii of 3' and 1.5', respectively.

Fig. 3.— The ASCA SIS spectrum of GRS 1758–258 is compared to the (non simultaneous) SIGMA data of Spring 1990 (Gilfanov et al. 1993). The solid line correponds to a fit to the ASCA data with a blackbody plus Sunyaev & Titarchuk Comptonization model (reduced $\chi^2$0.98, 870 d.o.f.). The best fit parameters ($\tau_{es} \sim 6$, $kT \sim 25$ keV) are consistent with the high energy data. The dotted line shows the soft blackbody component ($kT = 0.5$ keV).